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The growth of the sea star, Asterias rubens, and its role as benthic predator in Kiel Bay*

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Abstract

The determination of the age of individual sea stars (*Asterias rubens*) by means of length measurements or identification of growth rings in the calcareous skeleton presents great difficulties. Age-determinations are, however, the prior condition to growth calculations. For the determination of growth parameters L_∞, K and t_0 of the VON BERTALANFFY growth equation by means of the modal class progression analysis monthly dredging samples were taken in 12 profiles across the mouth of the Eckernförde Bay. Sea stars, which were exposed to lower temperatures during the first months after onset of growth, reach a larger asymptotic length than those exposed to higher temperatures. – By means of parallel diving observations to the dredging the mean biomass of *Asterias* in Kiel Bay was estimated to be about 32000 tons. Assuming a daily food uptake of 1 % of its own weight the sea star stock consumes about 120000 tons of food organisms per year. These data are discussed in context with biomass values of macrobenthos and cod in Kiel Bay. – The most striking finding, however, is the assumption of an intermediate phase, the "waiting stage", between the larval phase, serving propagation, and the growing stage, serving reproduction, in which tiny sea stars can remain for months waiting for a "free seat" in the ecological niche.

Zusammenfassung

Das Wachstum des Seesterns Asterias rubens und seine Rolle als benthischer Räuber in der Kieler Bucht

Die Altersbestimmung einzelner Individuen aufgrund von Längenmessungen oder Identifizierung von Zuwachsringen im Kalkskelett bereitet bei *Asterias rubens* große Schwierigkeiten. Sie ist aber eine wichtige Voraussetzung für Wachstumsberechnungen. – Die Parameter L_∞, K und t_0 der VON BERTALANFFY-Wachstumsgleichung wurden mit Hilfe der Analyse zeitlich aufeinanderfolgender modaler Klassen bestimmt. Ausreichendes Material dafür lieferten 12 Dredgeprofile, die in etwa monatlichen Abständen quer über die Eckernförder Bucht gefahren wurden. – Seesterne, die zu Beginn ihrer Wachstumsphase geringen Temperaturen ausgesetzt waren, erreichten eine größere asymptotische Endlänge als die Tiere, die bei höheren Temperaturen in die Wachstumsphase eintraten. – Parallel zu den Dredgehols wurden Proben von Tauchern genommen, um die Biomasse von *Asterias* in der Kieler Bucht abzuschätzen. Sie beträgt etwa 32000 Tonnen Lebendgewicht. Nimmt man eine

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tägliche Nahrungsaufnahme von 1 % des Körpergewichts an, verzehrt der Seesternbestand jährlich etwa 120 000 Tonnen Nährtiere. Diese Daten werden in Beziehung zu Biomasseangaben für den Dorschbestand und das Makrobenthos gesetzt. – Das vielleicht interessanteste Ergebnis ist die Annahme einer intermediären Lebensphase, zwischen der der Verbreitung dienenden Larvenphase und der Wachstumsphase. In diesem „Wartestadium", in dem die kleinen Seestern „auf einen freien Platz in der ökologischen Nische warten", können sie über Monate verharren.

Introduction

Though mainly restricted to salinities above 30 ‰ S, a few species of sea stars enter brackish waters. In the Baltic the asteroid *Asterias rubens* penetrates Kiel Bay and has its eastern border at the Darßer Schwelle with salinities down to 10 ‰. Successful reproduction was shown for salinities down to 15 ‰ S (KOWALSKI 1955, ARNDT 1964). As it can reach impressive biomass values locally, *Asterias rubens* is to be regarded as important resident in Kiel Bay, which must not be neglected in food web calculations.

When dealing with the ecological role of sea stars most authors have stressed the negative role these benthic predators play from the human point of view, as pest in oyster culture (GALTSOFF and LOOSANOFF 1939) and coral reefs (ENDEAN 1974) or as competitor with exploited demersal fish stocks (BLEGVAD 1930).

So far, little emphasis has been laid on the autecology of *Asterias rubens*. The purpose of this investigation is to give a contribution to this problem.

Material and Methods

A survey based mainly on dredgings was carried out almost monthly from April 1975 to September 1976 and in the summer of 1977 in different areas of Kiel Bay, especially in the shallower parts. For the investigation on growth of *Asterias* monthly samples were taken in 12 profiles across the mouth of the Eckernförde Bay (Fig. 1) providing a rich material of more than 51 000 individuals measured and weighed.

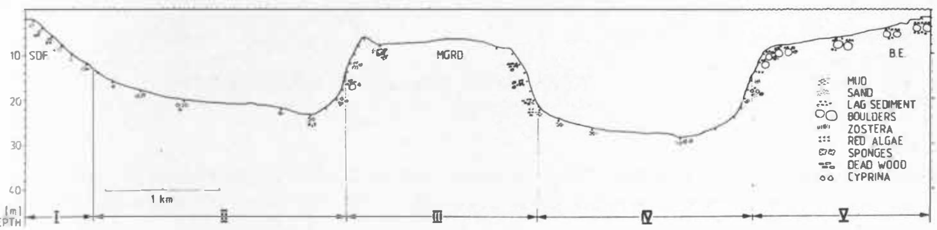

Figure 1

Profile of the mouth of the Eckernförde Bay sampled almost monthly for growth calculations of *Asterias rubens*. Vertical lines mark borders of the five subareas distinguished.

*) SDF = Surendorf, MGD = Mittelgrund, B. E. = Boknis Eck

Length was measured from the tip of one arm to the opposite interradius, thus making a rapid handling possible. From subsamples of sea stars of all size groups the mean percentage of dry weight and organic matter was calculated.

The gear used was a teethed triangular dredge, each side being 0.37 m long. The net had a mesh size of 20 mm. It was protected by a thicker outer net. For each haul the dredge was towed 3 minutes with a speed of 2 knots. The area swept by the dredge was 72 m². Thus the catch per swept area could easily be determined. Not known, however, is the percentage of sea stars remaining on the path of the dredge. For biomass estimations this had to be checked. Thus diving observations were carried out parallelly to the dredging, collecting the sea stars from 5 to 20 m² separately. This procedure was repeated on 4 types of sediments, namely lag sediment, sand, muddy sand/sandy mud, and mud (Fig. 2).

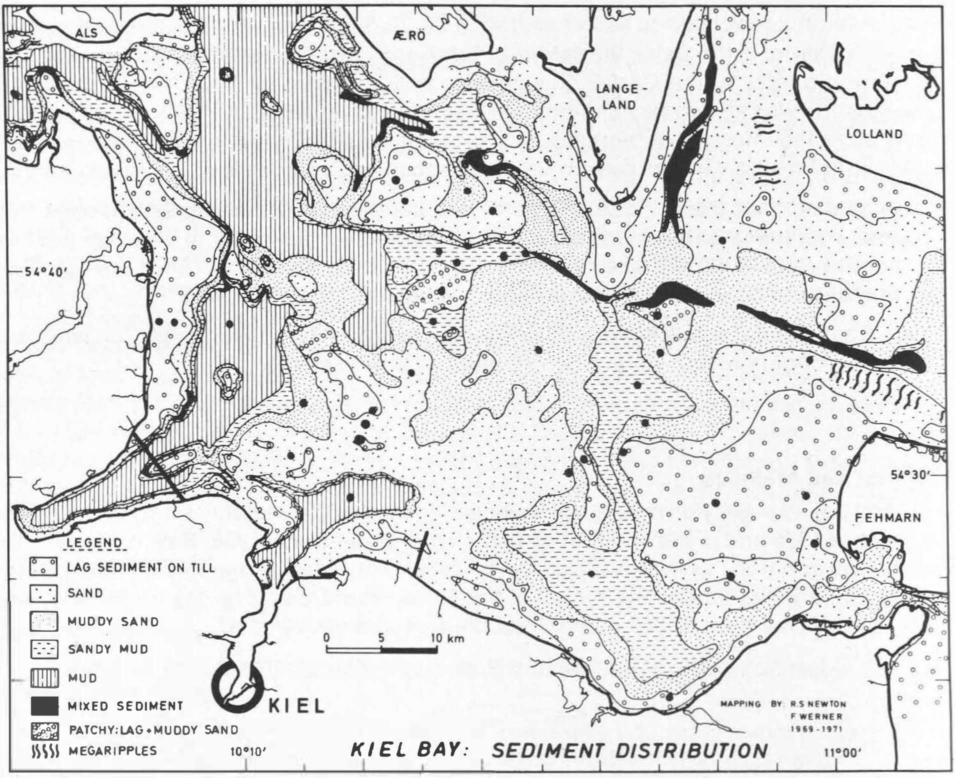

Figure 2

Sediment distribution in Kiel Bay. Filled dots mark dredging and diving stations, thick lines give positions of transect across the mouth of the Eckernförde Bay and three further dredging grounds

Furthermore, the sampling was carried out at 4 different depth ranges: 0 to 10.0m, 10.1 to 15.0 m, 15.1 to 20.0 m, and deeper than 20 m. From the sampling done by divers, correction factors were derived for the 4 sediment types. By dividing the results of the dredging survey by the corresponding correction factor, an estimate of the biomass can be extrapolated for the various areas. On lag sediment the dredge took 26.08 ± 15.88 % of the sea stars present, on sand it removed 32.25 ± 3.88 %. Thus for lag sediment the correction factor turned out to be 0.2608, for sand 0.3225. On the finer

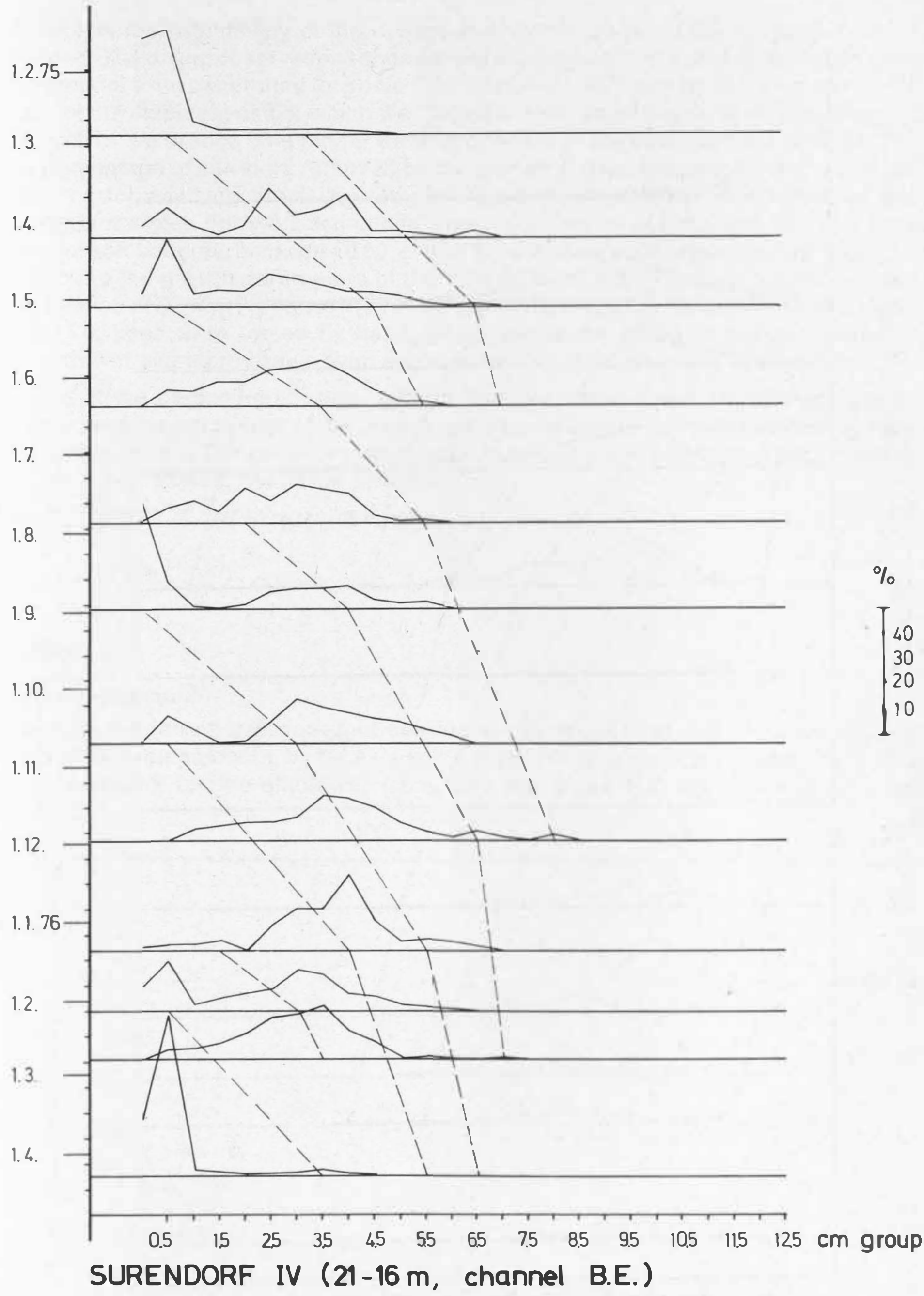

Figure 3a

Length-frequency-distributions of the sea star, *Asterias rubens*, arranged sequentially in time from 12 profiles across the mouth of the Eckernförde Bay, sampled almost monthly from February 1975 to April 1976 with two of the five subareas distinguished. Peaks of modal classes of "broods" of sea stars are joined by hand, the resulting lines being thought to reflect growth

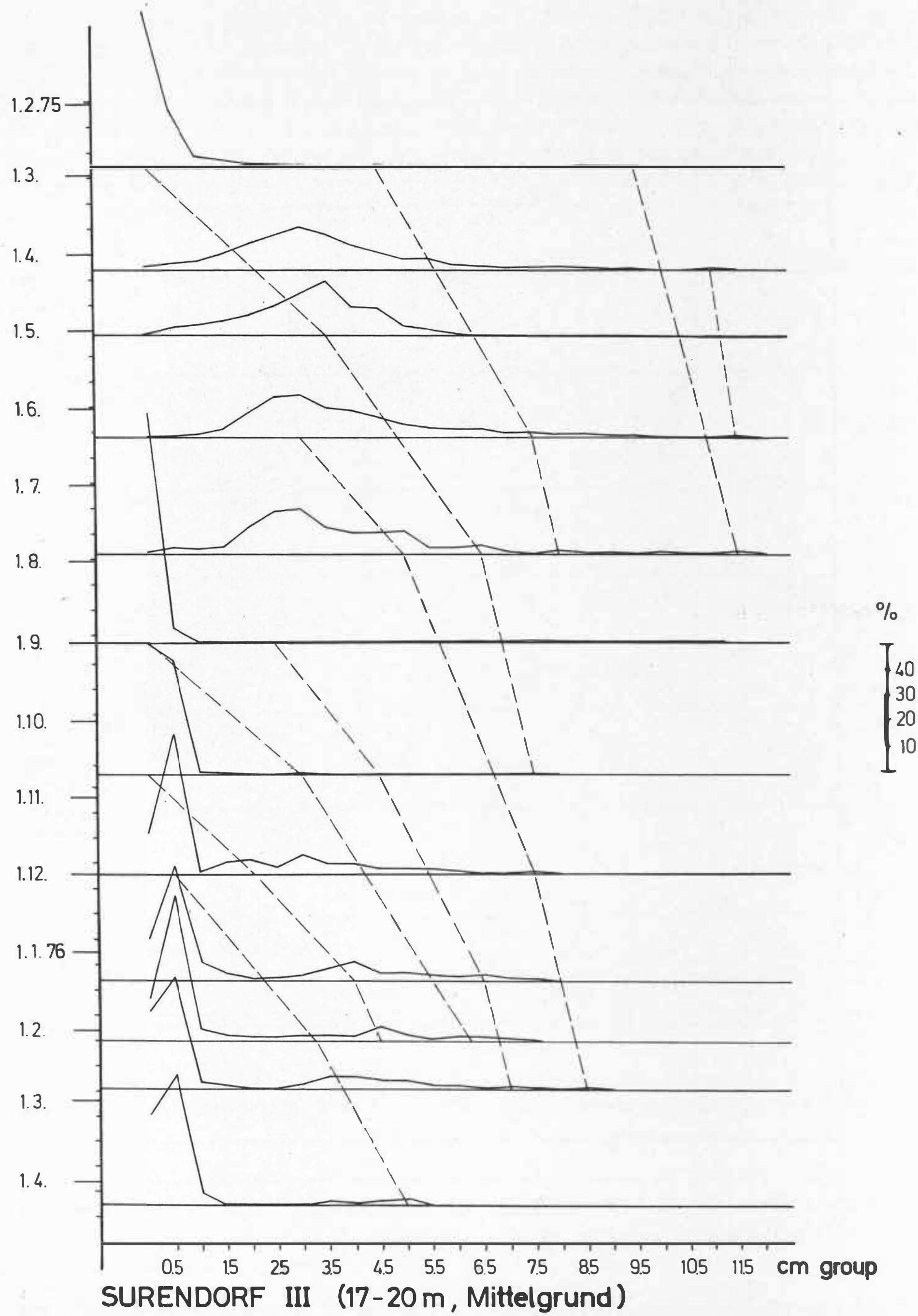

Figure 3b

For explanation see Figure 3a

sediments the catchability of the dredge was worse, because the net tended to be clogged. The diving observations showed that the net was towed on a straight line over the ground, even penetrated for some 5 to 10 cm, but – as it was quickly clogged – only pushed the sediment aside, which was found to form small deposits on both sides of the path of the dredge. The higher the muddy share in the sediment, the smaller was the percentage of sea stars removed by the dredge. It even happened that the dredge did not catch anything, the diving samples, however, showed 4.9 ± 15.1 g wet weight per square meter. For the calculations a correction factor of 0.105 was used for both types of soft bottoms, because 10.50 ± 9.78 % of the sea stars present were taken. To determine the growth parameters of the VON BERTALANFFY growth equation in the formulation of BEVERTON and HOLT (1957), the modal class progression analysis was used, i.e. lines were traced by hand, which joined the peaks of modal classes of "broods" of sea stars drawn from samples arranged sequentially in time (Fig. 3).

Length at the beginning of each "growth line" was then given an arbitrary age (0 month), and the parameter of the growth curves so obtained were determined by non-linear regression. The value of t_0 calculated in this way corresponds to the "onset of growth" (see below), not to the birthdate.

The VON BERTALANFFY growth function is:

$$L_t = L_\infty (1 - e^{-K(t - t_0)}).$$

Results

Catch composition

We always find two categories of sea stars, the small ones being almost always present in large numbers, by far exceeding those of the larger specimens. This holds true especially for the shallower parts with red algae and stones as substrates.

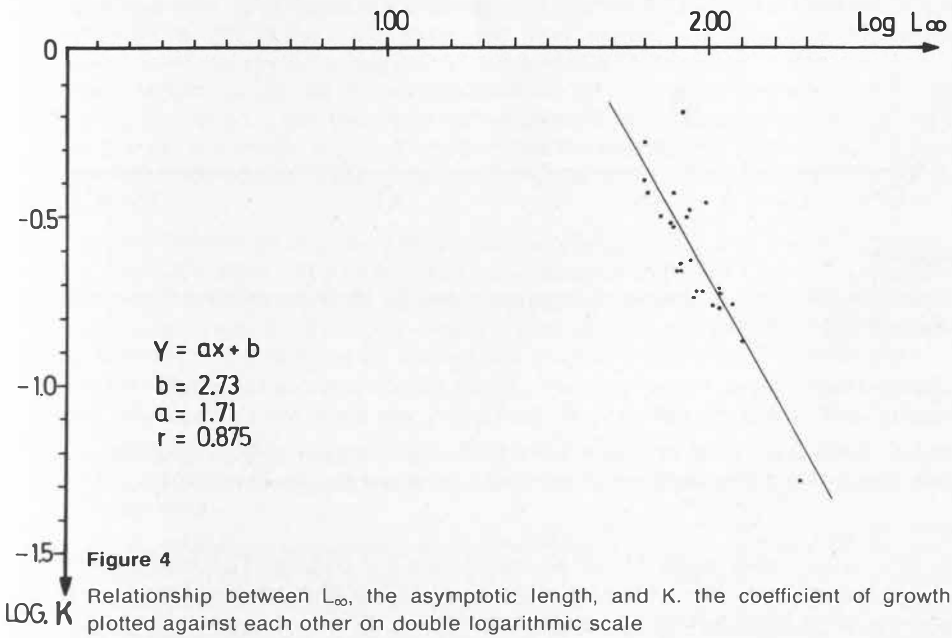

Figure 4

Relationship between L_∞, the asymptotic length, and K. the coefficient of growth, plotted against each other on double logarithmic scale

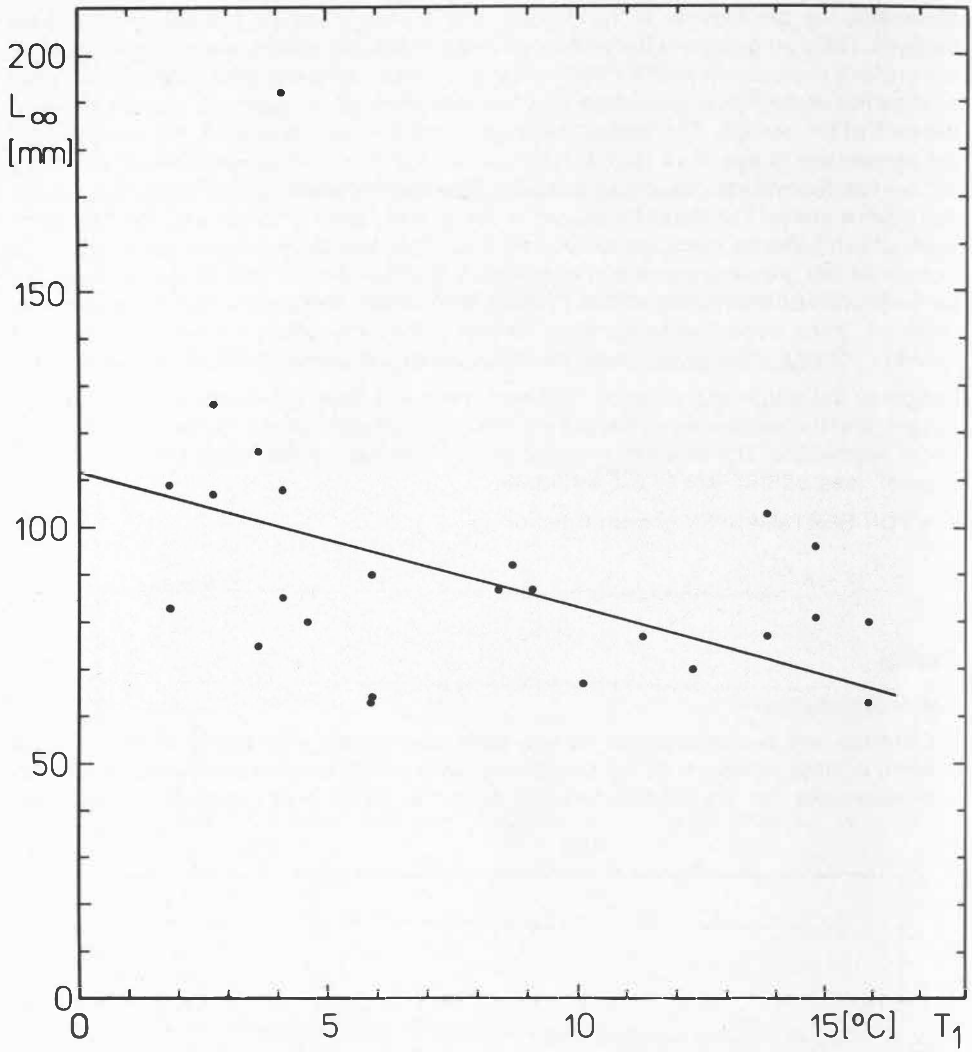

Figure 5

Relationship between L_∞, the asymptotic length, and the mean temperature in the first month after onset of growth

Masses of small specimens, however, cannot only be observed soon after the period of spatfall, but during the whole year. These tiny sea stars will be dealt with later.

Of the larger ones lower numbers were found. On the basis of their length-frequency-distribution 25 curves were drawn by hand, which are thought to reflect growth (Fig. 3).

Growth

At first, a plot was made of log K against log L_∞ (Fig. 4). The highly significant relationship shows that – as in fish – slow-growing sea stars become larger while fast-growing ones have a lower asymptotic length.

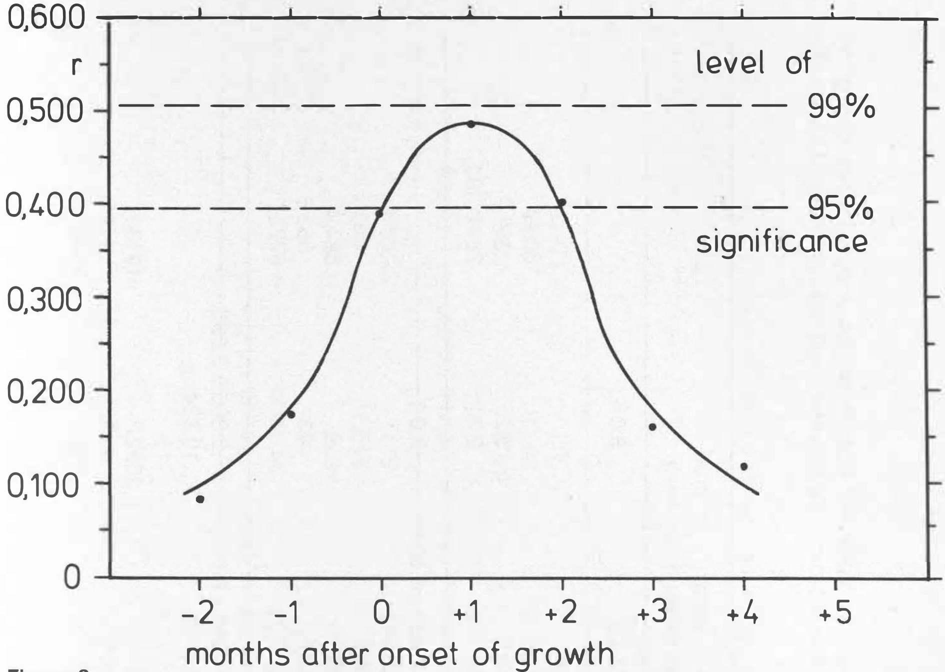

Figure 6

Correlation coefficients of L_∞ – temperature regressions plotted against time in months since onset of growth

The question arises: what leads to the differences in growth? It is almost trivial to state that temperature affects the metabolism and thus feeding and growth. Besides the well-known seasonal rhythms (HANCOCK 1955, MACKENZIE jr. 1970) it is checked, if asymptotic length is related to temperature in any specific period of life. The relationship between L_∞ and the mean temperature in the first month after estimated onset of growth is closest (Fig. 5). To both sides the correlation coefficients, plotted against mean temperature in the months since onset of growth phase, decrease (Fig. 6).

For an overall estimation of growth the preliminary mean of L_∞ and K was calculated (see also NAUEN in prep.). The mean asymptotic length was 89 ± 13 mm. This equals a diameter of about 150 mm and a mean wet weight of 40 g. K, the coefficient of growth, was 2.94 ± 1.9 on a yearly basis. This means that growth is very fast once it has started, making *Asterias* reach 95 % of its asymptotic length in little less than one year.

Biomass

Biomass values for the four sediment types and depth ranges distinguished are compiled in table 1. Values are given for wet weight per square meter and total wet weight in the area.

For lag sediment a mean wet weight per square meter of 9.13 ± 1.03 g (standard error) was estimated corresponding to 5500 tons[1]) of sea stars in the whole area. For sand the results are 14.81 ± 1.03 g and 12500 tons respectively. On muddy sand/sandy mud the standing stock was estimated as 14.3 ± 1.9 g wet weight per square meter and

Table 1

Mean biomass values of 16 sub-areas of Kiel Bay distinguished for 4 sediment types and 4 depth ranges ± standard error in g/m² wet weight for *Asterias rubens*, standard deviation, swept areas (SA) sampled in m², area in km², and total biomass of each sub-area in tons wet weight.

Depth range m		lag sediment	sand	muddy sand/ sandy mud	mud	Σ
0 – 10.0	g/m²	5.660 ± 1.674	8.360 ± 1.628	12.2[1])	8.0[1])	
	s	7.297	6.905			
	months	19	18			
	SA	5240	13396			18636
	area	195.9	197.5	3.7	0.2	397.3
	tons	1109	1651	45	2	2807
10.1 – 15.0	g/m²	13.600 ± 6.300	10.940 ± 3.349	12.229 ± 1.534	8.0[1])	
	s	12.600	13.395	5.943		
	months	4	16	15		
	SA	349	4822	3100		8271
	area	239.0	277.8	32.7	4.3	553.8
	tons	3250	3039	400	34	6723
15.1 – 20.0	g/m²	10.752 ± 5.187	25.668 ± 7.146	23.848 ± 6.030	8.000 ± 3.096	
	s	7.335	14.291	23.352	10.724	
	months	2	4	15	12	
	SA	408	544	6486	2692	10130
	area	88.3	286.1	497.1	42.3	913.8
	tons	949	7344	11855	338	20486

> 20.0	g/m²	2.258³)	5.42²)³)	2.686 ± 1.197	1.648 ± 0.832	
	s		15.03	2.933	3.000	
	months		1	6	13	
	SA		12	1742	4016	5770
	area	77.3⁴)	81.0	405.1	319.7	883.1
	tons	175	439	1088	527	2229
Σ	g/m²	9.131 ± 1.032	14.807 ± 1.034	14.264 ± 1.857	2.458 ± 0.650	11.734
	s⁵)	5.159	6.375	11.140	3.252	8.283
	SA	5997	18774	11328	6708	42807
	area	600.5	842.4	938.6	366.5	2748
	tons	5483	12473	13388	901	32245

¹) areas not sampled, 0.3 % of total area of Kiel Bay
²) diving observations only, standard deviation not included in mean standard deviation for sand
³) rate of decrease 21 %
⁴) including 44.5 km² mixed sediments
⁵) mean standard deviations and standard errors derived from fewer values than mean biomass per square meter

13400 tons for the whole area. Mud yielded lowest biomass values averaging 2.46 ± 0.6 g per square meter and 900 tons for all depth ranges.

Thus a biomass of about 32000 tons of sea stars is estimated for Kiel Bay.

From 179 samples the contents of dry matter was calculated to be 16.99 ± 0.29 % (standard error). The standard deviation was 3.92. From the same number of samples organic matter was calculated to be 48.68 ± 0.52 % of dry weight, the standard deviation being 6.90.

Predation

From literature data it is assumed that a sea star eats daily 1 % of its own weight (FEEDER 1970). Thus 42 g wet weight per square meter and year of food organisms are required to sustain the sea star stock.

Discussion

1. The estimate of biomass is rather crude in spite of the correction factors for the limited catching properties of the dredge. Apart from the limitations of the gear, still another factor must be considered when discussing the reliability of biomass estimates, namely the patchiness of distrubution as was demonstrated by ANGER et al. (1977) for an *Asterias* population in Lübeck Bay. This is also reflected in quite high standard deviations calculated for the dredge samples as well as for the ones taken by divers. On the basis of the above reservations a mean biomass of 32000 tons of *Asterias rubens* is estimated. Provided a daily food uptake of 1 % the sea star stock consumes some 120000 tons of food organisms per year. This equals a yearly predation of about 42 g wet weight per square meter in Kiel Bay.

For the deeper parts of Kiel Bay ARNTZ & HEMPEL (1972) estimated the cod stock in the *Abra alba* community at about 10000 to 15000 tons. They calculated that in 1968 at least 50000 tons of macrobenthos and 100000 tons of *Cyprina* plus 15000 tons of fish had been consumed by cod. This means a daily food uptake of about 3 % or 52 g wet weight of macrobenthic invertebrates (excluding *Cyprina*) per square meter for the deeper parts of Kiel Bay, derived from 24 stations (see ARNTZ 1971), where on 6 cruises each time 3 VAN VEEN grabs (0.1 m^2) were taken.

Since then the importance of *Asterias* in these areas seem to rise (see Table 1). Part of this effect may, however, be due to the fact that grab samples tend to underestimate especially larger sea stars (SKJAEVELAND 1973). From these rough calculations it seems that cod consumes an only slightly higher percentage of macrobenthos in Kiel Bay than sea stars do. However, the relative importance of these two main predators in different depth zones differs.

In the shallower parts down to 15 m the sea stars are dominating whereas in the deeper parts this holds for cod, as was already suspected by ARNTZ and BRUNSWIG (1975), though even in this area *Asterias rubens* may reach about two thirds of its total biomass by a small number of large individuals. *Asterias* exhibits the highest relative and absolute biomass values up to about 84 % of its total biomass in medium water depths (10 to 20 m). Thus the pattern of depth distribution for the sea stars resembles the one found by ARNTZ and BRUNSWIG (1975) for macrobenthos. In shallower water, where the relative biomass values are a little lower than in medium depths the sea stars tend to be smaller. Here the majority of tiny sea stars are found, probably because of suitable substrate, namely red algae, small stones, and boulders to which they live closely attached.

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[1]) differences to table 1 are caused by rounding up.

Table 2

Mean biomass values of different areas ± standard error in g/m² dry weight for *Asterias*, other macrobenthic invertebrates and cod.

Area	Biomass	Species	Gear	Author
Borgenfjord	6.09 ± 1.34	*Asterias*[1])	Diving	SKJAEVELAND (1973)
Limfjord	0.73 ± 0.18	*Asterias*	0.1 VAN VEEN grab	PETERSEN & BOYSEN JENSEN (1911)
Kiel Bay	1.99 ± 0.13	*Asterias*	dredge and diving	NAUEN diese Arbeit
Kiel Bay	4.56[2])	Molluscs[3])	0.1 VAN VEEN grab	ARNTZ (1971)
Kiel Bay	2.74[2])	Crustacea and Polychaetes	0.1 VAN VEEN grab	ARNTZ (1971)
Kiel Bay	0.89[2])	*Gadus morhua*	landing statistics	ARNTZ and HEMPEL (1972)

[1]) including about 0.4 g *Ophiura texturata* and *O. albida*
[2]) calculated from wet weight with the aid of coefficients given by BRUNSWIG (1973)
[3]) excluding *Cyprina*

2. Most striking are the enormous numbers of tiny sea stars exceeding those of the larger ones mainly in the shallower parts of Kiel Bay. Thus a "waiting stage" has to be assumed in order to explain the apparent contradiction that there is only one spawning period from late May to June and sometimes July and the fact that every month tiny sea stars are caught in high numbers. Thus we have to accept the existence of an intermediate stage between the larval stage, which serves propagation, and the growth stage, which eventually serves reproduction (Fig. 7).

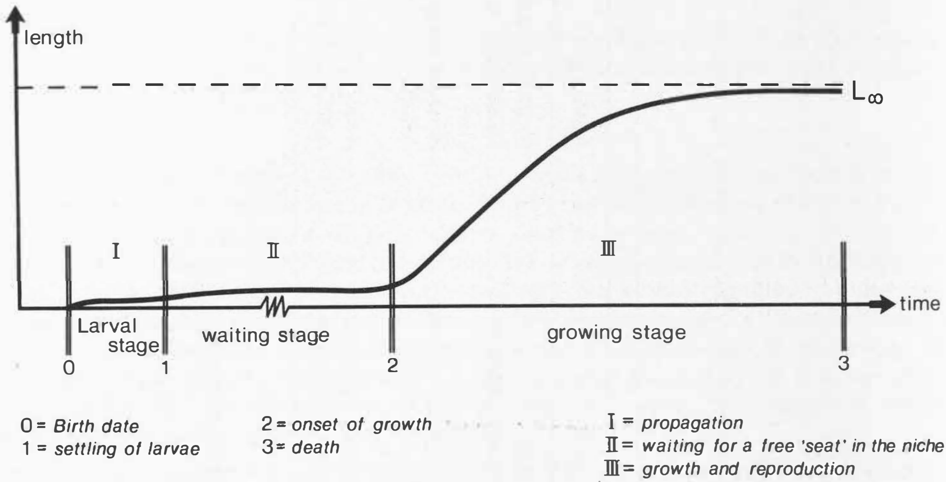

Figure 7

Schematic representation of the history of *Asterias rubens*. 0 = birth date. 1 = settling of larvae, 2 = onset of growth, 3 = death. The biological meaning of the three life phases distinguished is: I = propagation, II = waiting for a free ,,seat'' in the ecological niche, III = growth and reproduction

This "waiting stage", as it could be called, is formed of postmetamorphosed sea stars, which have not yet started feeding on macrobenthic invertebrates. They are assumed to feed on detritus including some meiofauna, which should be permanently accessible in sufficient quantity. This "waiting stage" could be one of the reasons why sea stars – ecologically speaking – are a successful group. Further investigations should reveal the physiological mechanisms of the high adaptability of *Asterias* to the environment.

Acknowledgement

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